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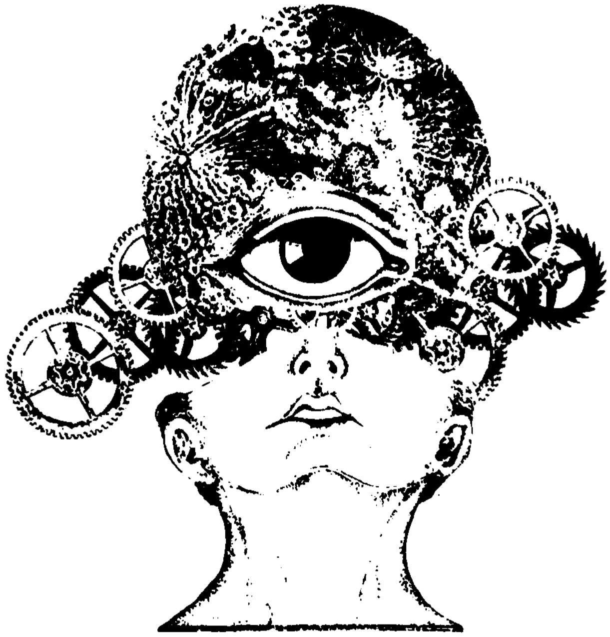
VISUAL SEARCH IMPROVES WITH DETECTION SEARCHES DECLINES WITH NONDETECTION SEARCH

Walter Schneider and Arthur D. Fisk

REPORT No. 8004



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Experiments examined improvements in target detection performance in visual search as a function of number of detection searches versus nondetection searches. The hypothesis questioned whether the number of times a detection state occurred versus the number of times the search process was executed determined the improvement rate. Subjects trained with consistently mapped (CM) targets with different numbers of detection opportunity searches versus nondetection opportunity (no target) searches. A multiple frame procedure

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20. was used in which subjects searched through 12 frames with 4 characters each for a single target. After training blocks subjects were tested with a target presented on every trial. The results show: (1) detection accuracy is primarily a function of number of detections as opposed to number of searches; (2) nondetection searches decrease detection accuracy; (3) as few as 10 CM detections can result in significant improvement in performance; (4) there may be some minimum processing time necessary after detection in order for the detection to result in improving later detection performance; and 5) the improvement from high detection probability training shows positive transfer to both low and high probability target search.

Visual Search Improves with Detection Searches,

Declines with Nondetection Search

Walter Schneider and Arthur D. Fisk

Report 8004

Human Attention Research Laboratory

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Running head: Detection versus search

Abstract

Experiments examined improvements in target detection performance in visual search as a function of number of detection searches versus nondetection searches. The hypothesis questioned whether the number of times a detection state occurred versus the number of times the search process was executed determined the improvement rate. Subjects trained with consistently mapped (CM) targets with different numbers of detection opportunity searches versus nondetection opportunity (no target) searches. A multiple frame procedure was used in which subjects searched through 12 frames with 4 characters each for a single target. After training blocks subjects were tested with a target presented on every trial. The results show: 1) detection accuracy is primarily a function of number of detections as opposed to number of searches; 2) nondetection searches decrease detection accuracy; 3) as few as 10 CM detections can result in significant improvements in performance; 4) there may be some minimum processing time necessary after detection in order for the detection to result in improving later detection performance; and 5) the improvement from high detection probability training shows positive transfer to both low and high probability target search.

In the visual search experiments reported by Schneider and Shiffrin (1977), and Shiffrin and Schneider (1977), performance of subjects was shown to change both qualitatively and quantitatively with extended training. This performance change, from a slow serial attention demanding controlled processing search to a fast parallel automatic detection process, was dependent upon a consistent mapping (CM) training procedure. In CM training, memory set items (targets) never occur as distractors and distractors are never memory set items. In varied mapping (VM) training an item may occur as a target on one trial and function as a distractor on the next. That is, targets and distractors are chosen randomly from the same set of items. With VM training there is little, if any, improvement in performance with extended practice. That visual search performance improves in CM conditions was shown by Neisser (1963). At present we have little information as to what determines the rate of improvement.

The present report examines two alternative factors which may be important elements in automatic process development in CM training. Accuracy of detection may be determined by the number of times a particular character is searched for or, alternatively, it may be determined by the number of times the item is detected. The frequency of search measures the number of times the search process was executed. The frequency of detection measures the number of times the search process was in the detection state. The experiments that follow investigate the importance of the detection state of memory in relation to the development of an automatic process. If the joint occurrence of stimulus and response is important for the development of an automatic process then performance should be a function of detections and not searches.

Experiment 1

Method

Subjects. Nine subjects from the University of Illinois introductory psychology subject pool were used in the experiment. Their participation partially fulfilled a course requirement. All subjects had normal or corrected to normal 20/20 vision, were right handed and reported English as their native language.

Equipment. The experiment was controlled by a Digital Equipment Corporation PDP 11/34 computer. The computer was programmed to present the appropriate stimuli, collect responses, and control timing of the display presentation. The stimuli were presented on Tektronics Model 604 and 620 cathode ray scopes which contained P-31 phosphors. Each subject wore a headset through which white noise (80 db) and an error tone were carried.

Stimuli. The characters used in the present experiment were nine upper case letters of the English alphabet. The characters were constructed from dots on a rectangular grid 32 dots wide by 48 dots high with the characters subtending .58 degrees in height and .52 degrees in width. The refresh rate of the dots making up the stimuli was 10 msec. The display of the characters was divided into frames where each frame consisted of four characters positioned to form a square around a center fixation dot. The subjects sat 45 cm from the display. With fixation at the central dot, the visual angle subtended by the characters was one degree.

The letters used were: A, C, D, E, M, R, S, U, and Z. The choice of the above letters was based upon the results of a series of experiments indicating that these letters were the most equally confusable as a group given the font and multiple frame presentation of the present experiment. Also, the above letters were least susceptible to subject differences and least susceptible to confusability changes due to removal of any letter from the set. This discussion should not imply that the chosen letter set was devoid of item effects (i.e., differential ease of detection of the letters).

Trial Sequence. In the current experiment, each trial consisted of the following sequence. 1) The memory set display. This display was presented in the upper left hand corner of the scope and contained the target item (memory set size was always one). In addition, accuracy feedback was presented in this display. This feedback was a two digit number presented to the right of the memory set display and was separated from the target item by approximately 1 degree visual angle. The feedback was the average accuracy during a given block of trials and was initialized to zero prior to each trial block. (Perfect performance was represented by a 99.) The subjects were given up to 30 seconds to study the target item and initiate the trial sequence. The subjects initiated the remaining part of the trial sequence by a button push with the index finger of their left hand. This button push terminated the memory set display. 2) Following the memory set display and preceding the frame sequence, was the presentation of the fixation dot for 500 msec. This provided a fixation point corresponding to the central fixation dot of the frame sequence. 3) The frame sequence consisted of 12 frames presented in rapid succession. Each frame was composed of four letters presented for 80 msec followed immediately by four random dot masks presented in the same display positions as the letters for 30 msec. These elements were positioned to form a square around a center fixation dot. The display time of the letters plus the display time of the masks yielded a total frame time of 110 msec. The distractor characters were randomly distributed on each frame with the restriction that no character appeared in the same display position on two successive frames.

If the trial was a positive trial, the target item was presented once during the frame sequence. The target could not occur during the first two or last frame of the sequence. The target frame, as well as the display location of the target within that frame, was randomly determined. The subjects' task was to indicate the target's location by pushing one of four buttons with their right index finger. These buttons also formed a square and represented a one-to-one mapping of display position and response button. Any response less than 150 msec or greater than 2.5 seconds subsequent to the target frame was considered invalid and deleted from the reaction time analysis. The subjects were instructed to "guess" the correct response at the end of the frame sequence if no target was detected. On negative trials subjects could not have detected the target and hence had to "guess" any position.

At the end of each trial the subject received an error tone if an incorrect response was made. Also, the subject received a skill rating which corresponded to a given accuracy level for trials in which the target was present. The skill rating was indicated by flashing a light on the subject's response box. The skill ratings were: Ace - 100 to 90 percent correct (green LED); Expert - 89-80 precent correct (yellow LED); Average - 79-60 percent correct (red LED);

Table 1

Condition	CM1	CM2	CM3	CM4	VM
Times searched during training	6	6	20	20	20
Times target present during training	2	4	4	16	10
Detection rate during training	.33	.38	.45	.40	.41
Average total hits during training	4.6	10.6	12.6	44.8	28.7
Test data corrected accuracy scores	.47	.52	.52	.43	.40

and Novice - 59 percent correct and below (red LED). The skill ratings were printed below the four lights. Trials not containing targets were considered neither correct nor incorrect and did not enter into the accuracy rating. If a correct detection was made, a random dot pattern would appear to spin off the screen from the target's display location.

Design. The independent variables manipulated were: 1) the relationship between memory set and distractor set being either consistent (CM) or varied (VM) in its mapping; and 2) the search conditions. The search conditions are presented in Table 1 and refer to the number of times a character was searched for (presented in the memory set) versus the number of times it actually appeared in the frame sequence per block. One letter was assigned to each of the four CM search conditions with the other five being used as distractors and VM target items. Across the nine subjects each character was used in each CM condition one time. As can be seen from Table 1, on the average, half of the trials contained a target item. Each trial block contained 72 trials.

The experiment was divided into 2 parts. First, the subjects completed seven blocks of training under the above mentioned search versus detection schedule. Then one block of 100 trials was presented as a test of automatic processing development. For the test, a target occurred on every trial and an equal number of trials (20) was allotted to each of the previous search conditions. Both the training and test parts of the experiment utilized a within subject design. The training phase of the experiment required approximately two hours and the test phase one hour.

Results and Discussion

Table 1 shows the observed detection rates during the training and testing portions of the experiment. The hit rates indicate the corrected position detections (corrected = observed position detections - 1/3 errors). Subjects' detection performance was very poor in all conditions, ranging from .33 to .45. This resulted in the actual number of hits per subject being very low, ranging from 4.6 to 44.8 hits per subject during the entire training phase of the experiment. A test of the arcsin transformed test data showed no significant differences [$F(4,32)=1.52$, $p>.21$].

Insert Table 1 about here

The lack of significant differences in the present results suggests automatic processing develops slowly as a function of the number of detections. The maximum number of CM detections in any condition was 44.8. The present experiment may not be sufficiently sensitive to determine the effect of so few detections. If the total number of times of searching were the critical variable, a difference between CM4 (140 searches), and CM2 (42 searches) would have been expected. Hence, the present results are suggestive that the frequency of detection is a more important variable than the frequency of search. The next experiment addresses the same question as Experiment 1 but uses a frame time during the training which was expected to yield a higher level of detection.

Experiment 2

Method

Subjects. Eighteen students from the University of Illinois introductory psychology pool were used in the present experiment. Their participation partially fulfilled a course requirement. All subjects reported English as their native language, were right handed, and had normal or corrected to normal 20/20 vision.

Design and Procedure. This experiment was identical to the previous experiment except that the total frame time for the training phase was increased to 150 msec. This represented 120 msec for the character display and 30 msec presentation of the masks. Frame time was 110 msec during the test phase. Since there were 18 subjects, each letter was used in a given CM search condition twice.

Results and Discussion

The experimental results are presented in Table 2. The detection rate during training for each of the CM conditions was better than the VM detection rate. The test data shows a significant difference across conditions [$F(4,68)=7.97$, $p<.0001$]. Post hoc analyses show that all CM search conditions are better than the VM search. Detection search accuracy increased as a function of the number of detections with number of searches held constant. Given that there is an equal number of detections, increasing the number of nondetection searches significantly decreased performance (CM3 less than CM2 [$F(1,17)=9.104$, $p<.008$]). In fact, CM3 performance was worse than CM1 performance although the statistical comparison was non-significant. It appears that doubling the number of detections did not compensate for increasing the number of nondetecton searches by 3.8 times. This suggests that two searches without a detection may decrease learning as much as a single successful detection increases it.

Insert Table 2 about here

Since the testing phase of this experiment presented a target on every trial, it is possible that the superior performance in the high detection rate conditions is due to a greater similarity of the training target ratio to the test target ratio, as opposed to an increase in number of detections. A reason to expect differential training and test target ratios to result in poorer performance is suggested by the vigilance literature. Typically, reductions in target signal probability affect subjects' response criterion, reducing subjects' willingness to respond as the signal probability decreases (Colquhoun, 1961; Johnston, Howell, and Goldstein, 1966). The effect of signal probability in the training phase of the experiment might carry over to the test phase of the experiment (Colquhoun and Baddeley, 1967; Baddeley and Colquhoun, 1969). Subjects in the CM3 (4 targets in 20 searches) may have increased their response criterion, and simply "guessed" more often on trials when the target was present. In this way training in low target probability conditions may have increased subject criterion and resulted in lower hit rates during the test

Table 2

Condition	CM1	CM2	CM3	CM4	VM
Times searched per block during training	6	6	20	20	20
Times target present per block during training	2	4	4	16	10
Target present ratio during training	.33	.67	.2	.8	.5
Detection rate during training	.72	.73	.67	.72	.58
Total detection opportunities/ nontarget searches	14/28	28/14	28/112	112/28	70/70
Average total hits during training	10.1	20.4	18.8	80.6	40.6
Test data corrected accuracy scores	.64	.71	.57	.72	.45

trial. However, since all of the above conditions were randomized between trials and subjects expected target probability to be .5, it is unlikely that differential strategies developed. A second reason for better performance with greater similarity of training and test target ratio is that subjects developed different strategies in the high probability target search conditions that carried over to the test search condition. Shaw (1979) has shown that in a 2 channel detection experiment with a target on every trial subjects should utilize a strategy of allocating all the resources to one channel and then guess the other channel if they do not detect a target. However, such a strategy is less effective with four channels as in the present experiment. Also, in the present experiment subjects were not informed about the differential target probabilities but only that the probability of the target was .5.

The present data indicate that as few as 10 CM detections can result in better detection performance than VM search. The CM1 condition had an average of 10.1 detections during the two hours of training. In the VM search condition the subject received an average of 8.1 detections per target letter during the two hours of training. The significant difference between CM1 and the VM condition (.64 versus .45 detection accuracy, resepectively, $\underline{p}<.01$) indicates that even a small number of CM training trials can result in significant improvements in detection accuracy.

The present data are difficult to interpret in terms of a simple strength concept of CM development. The lack of a significant difference between the CM2 and CM4 condition (.71 versus .72) may have been due to CM performance reaching an automatic process performance ceiling[1] or a lack of sufficient range of tested number of detections (19 versus 80, respectively).

Differences between CM1 versus CM2 (though non-significant), and CM3 versus CM4 (significant, $\underline{p}<.01$), conditions indicate that increasing the number of detection opportunities while holding the number of searches constant does improve performance.[2]

Increasing the number of nondetection searches significantly decreases detection accuracy. In conditions CM2 and CM3 subjects had 28 detection opportunities and 14 and 112 nondetection searches, respectively. The additional nondetection searches resulted in a decrease of detection accuracy from .71 to .57 ($\underline{p}<.01$). Comparing CM1 to CM3 shows that doubling the number of detection opportunities while quadrupling the number of nondetection searches resulted in a decline in test rate (.64 to .57). This suggests that four nondetection searches can be as detrimental as an additional detection is beneficial. Since CM3 performance was superior to VM performance ($\underline{p}<.05$) the detrimental effects of nondetection searches did not completely cancel the beneficial effects of CM training.

These present data confirm the conclusion of Experiment 1 that the number of detections and not number of searches is the important factor determining the development of an automatic process. In addition, the present results indicate nondetections are detrimental to automatic process development.

The results of Experiments 1 and 2 suggest that a minimum detection time may be necessary to develop automatic detection. The CM4 condition in

Experiment 1 was not significantly different from VM even though subjects averaged 45 detections during training. This can be contrasted with the CM1 condition in Experiment 2 in which subjects averaged only 10 detections but did develop significantly better detection capability than VM. The detection to nondetection search ratios in these two experimental conditions were 45/95 (CM4 Experiment 1) and 10/32 (CM1 Experiment 2), yet the test detection ratio performances were respectively .43 and .64. The CM4 condition had more detections and a higher ratio of detection to nondetection searches (.47 versus .31) than the CM1. If automatic detection improved as a function of frequency of detection or with the detection to nondetection ratio, the CM4 condition of Experiment 1 should have been better than the CM1 condition of Experiment 2. It is possible that not the ratio but the absolute number of nondetection searches determines CM development. However, this would predict that CM3 of Experiment 2 (122 nondetection searches) would be worse than CM4 of Experiment 1 (95 nondetection searches), which was not the case. We propose a minimum time may be required for a successful detection to improve automatic process development. In Experiment 1, with a training frame time of 110 msec, there may be sufficient time for detecting the target 40% of the time but the detection state is too brief to allow control processing to modify memory to improve later detection. When training frame time was increased to 150 msec the detection state was 40 msec longer, enabling control processing to modify memory, leading to improvements in detection performance.

When modeling the development rate of an automatic process the detection rate must be included as a parameter. But, we believe that perfect detection will not yield optimal learning. We expect the degree to which the observer is forced to utilize automatic processing influences the development rate. If, for example, each frame was presented at a one second rate, the observer would not be required to use automatic processing to perform optimally, and the development of automatic processing may be slowed. We have seen subjects who have run in a single frame condition (where subjects make a reaction timed response to each frame) for days without improvement until they were pressured to make fast responses even if error rates increased. Speed stressing the subject by controlling the processing time (per frame) in the multiple frame condition, may more quickly develop automatic processing (these questions are currently being investigated).

The present results suggest that learning takes place as a function of the number of times memory is in the proper detection state and how much time is available for control processing to be done during the detection state. There are a number of learning phenomena which support the present suggestion. Perceptual learning is speeded by emphasizing feature differences (Gibson, 1969). The emphasis results in more detection states and fewer non-detection states. Subjects learn faster if their performance is guided so they make fewer errors (Welford, 1976, chapter 6). This guiding would result in more occurrences of memory in a consistent proper performance state analogous to the present experiment's detection state. Recent results by Logan (1979) suggest that learning reduces if control processing resources are reduced. Logan found that when subjects combined a digit span task with a choice reaction time task, the improvement (measured by the slope reduction as a function of the number of alternatives) was slowed by the addition of the concurrent digit span task.

Table 3

	CM1	CM2	CM3	CM4	VM
Detection rate during 1st training period	.72	.70	.65	.67	.56
Detection rate during 2nd training period	.76	.79	.81	.75	.57
Average total hits during 1st training period	10.1	19.6	18.2	75.0	39.2
Average total hits during 2nd training period	10.6	22.1	22.7	84.0	39.9
Test (1st) data corrected accuracy	.61	.61	.60	.57	.43
Test (2nd) data corrected accuracy	.69	.71	.57	.68	.41

The present benefit of high detection search training could be interpreted as being due to the greater similarity of the training target probability (e.g., .67 or .80) and the test target probability (1.0). The next experiment utilized a target probability in the testing phase equivalent to the average target probability during training (50 percent). This directly tests the possibility of superior performance in the high detection condition due to greater similarity of training target ratio to test target ratio.

Experiment 3

Method

Subjects. Eighteen introductory psychology students from the University of Illinois were used in the present experiment. All met the criteria for subjects as described in Experiment 2. Participation in this experiment fulfilled a course requirement.

Design and Procedure. This experiment was the same as Experiment 2 except that a target was present on only 50 percent of the trials during the testing phase of the experiment. During the test each CM target was present on 20 trials as was a VM target. This necessitated that the test phase consist of 200 trials (as opposed to 100 in the previous experiment). The subjects participated in two training/test cycles.

Results and Discussion

Five subjects did not complete the experiment in the allotted time (three 50 minute sessions) and were excluded from the analysis. The experimental results are presented in Table 3. As in Experiment 2 all CM conditions showed a higher detection rate than VM with the difference increasing between the first and second training periods. The analysis of the test data shows a significant main effect of conditions at both the first and second test periods, [$F(4,48)=2.98$, $p<.028$ and $F(4,48)=5.5079$, $p<.001$], respectively. All CM conditions at the first test point differed from the VM condition with $p<.04$ in all cases and the CM conditions did not differ. (The results of the CM to VM comparisons were: CM1, $F(1,12)=19.65$, $p<.001$; CM2, $F(1,12)=6.65$, $p<.025$; CM3, $F(1,12)=5.35$, $p<.04$; CM4, $F(1,12)=7.70$, $p<.017$.) For the second test period, all CM conditions differed from VM with $p<.001$ for CM1, CM2, and CM4 and $p<.03$ for the CM3 condition. The difference between the CM3 and CM4 conditions approached statistical significance [$F(1,12)=2.85$, $p<.11$]. The data were extremely variable (except for VM performance) across the subjects which accounts for the lack of statistical significance between the CM conditions. The important contribution of the present experiment is that even with the change in target probability during the testing phase the general pattern of results from Exeriment 2 is present in Experiment 3. Detection accuracy decreases as a function of nondetections, as few as 10 CM detections can result in significant improvement in performance, and detection accuracy is primarily a function of number of detections not number of searches.

Insert Table 3 about here

In summary, the present results indicate: 1) detection accuracy is primarily a function of the number of detections as opposed to the number of searches; 2) nondetection searches are detrimental to later performance; 3) as few as 10 CM detections can result in significant improvements in performance; 4) there may be some minimum processing time necessary after detection in order for the detection to result in improving later detection performance; and 5) the improvement from high detection probability training shows positive transfer to both high and low target probability search performance.

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Footnotes

[1]The maximal CM performance for the present stimuli and frame time may have a ceiling of .75 target detection probability. Hence large differences in number of detections may result in only small improvements in performance.

[2]The lack of a significant difference between CM1 and CM2 is most likely due to a lack of power of the present statistical comparison and a restricted range of test values. In order to reach the .05 level of significance the underlying distributions in CM1 and CM2 would require means that were at least 1.1 standard deviations (d') apart or an 11% difference. It is unlikely that an automatic process can reach the .75 probability detection rate required in only 20 detections in the present conditions. Hence, the present differences suggest that increasing the ratio of detection to search opportunities from 14/42 to 28/42 improves performance, more powerful tests will be required to settle the issue.

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